PART II. RESULTS OF THE FIRST MEASUREMENTS IN THE MODULATIONLESS MODE

N. I. Kobanov and D. V. Makarchik

Institute of Solar-Terrestrial Physics, Siberian Division, Russian Academy of Sciences, Box 4026, Irkutsk, 664033 Russia

e-mail: kobanov@iszf.irk.ru; d_makarchik@iszf.irk.ru

Received January 18, 2001

Abstract—The results of the first measurements of the differential ray velocity and the longitudinal component of the magnetic field strength performed in the modulationless mode by using the polarization optics of standard CCD photodetectors are presented. The observations were of experimental character and confirmed the main advantages of the modulationless technique—a significantly reduced (by a factor of up to 40) influence of the spectrograph noise instabilities and the Earth’s atmosphere on the measurement results.

OBSERVATION TECHNIQUE AND SOFTWARE

The first observations according to the technique described in [1] were performed in September–October 1999 by using a linear CCD array on a horizontal solar telescope of the Sayan observatory [2] and were continued in September 2000 (with a CCD matrix as well). These observations were of testing character and were aimed at studying the main characteristics and features of this method. Observations by using the conventional technique (imitation of the Doppler compensator mode) were performed with the same linear CCD array for comparison.

In measurements of the differential ray velocity, the orientation and parameters of prism \( L \) [1] were selected such that the velocity difference for two sun surface areas separated by a 12” angular distance along the equator with dimensions of 2” \( \times \) 1.5” could be measured. In order to track with precision the sun area selected, a photoelectric telescope guide was used. An image shift due to the sun rotation was canceled by slow scanning in the same direction with a velocity of \( \sim 9.5”/h \).

The linear dispersion in the fifth order of the diffraction spectrograph was 3 mm/Å. As is known, at inclined incidence of rays, the telescope’s mirrors introduce a spurious linear polarization usually called the “instrumental” one. A reduction of its influence on measurements of the differential ray velocity was achieved by rotating the polarization prism \( L \) by an angle of 3º–5º about the optical axis of the telescope; in this case, the intensities of spectral components become equal.

Observations were performed on a linear CCD array (TCD 1301 D, Toshiba Company, 29 mm long, 3700 pixels: the pixel height and width are 200 and 8 \( \mu m \), respectively) with a program developed in the Delphi software environment for the Windows 95/98 operating system. All control parameters for the CCD array operation described below are specified in the program interface, simplifying the observations for a user and making it possible to change promptly the observation modes. The data storage time and the name of the file of the calculated signals are specified in one of the program’s window. An on-line spectrum updated 30 times per second and the position and width of the electronic slits are displayed in the other window.

Figure 1 shows this window with the working portion of the on-line spectrum near the 485.7-nm Ni line (in the region of superposition of the spectral components) displayed on the monitor screen and the positions of three electronic slits in the line: the central slit in the line core and two side slits (red and blue) in the red and blue line wings. In several modes of on-line spectrum viewing, we can use an enlarged scale in order to raise the accuracy in positioning the electronic slits.

The positions of the electronic slits with respect to the pixels on the CCD array remain unchanged during modulationless observations, and signals are processed using the formulas presented in Part I of this paper [1]. The integral radiation flux from the portion of the spectrum line intercepted by the corresponding electronic slit is considered a signal from this slit. Thus, the data arrays of signals of the differential ray velocity and magnetic field strength are calculated, written into a file, and are subsequently translated into the velocity and magnetic-field strength values.

When operating in the mode of Doppler compensator imitation, ray velocities are measured by the shift of the spectrum line center (Doppler effect). The positions of the symmetry axes of two following-up electronic slits are indicated by a cursor on the viewing screen (Fig. 1). In the initial position, the integral radiation fluxes in each slit are equal, and, when a spectral line...
shifts as a result of the Doppler effect, the fluxes become unbalanced.

The program operation is aimed at changing the positions of the electronic slits so as to remove this imbalance. The recorded values are the shifts of the symmetry axes of the slits required for this purpose. Subsequently, a change from the shift of the line center ($\Delta \lambda$) expressed in pixels of the linear CCD array to a shift in ångströms occurs, and the ray velocity (in meters per second) is calculated with the formula $V = (\Delta \lambda / \lambda) c$ ($c$ is the velocity of light). The widths of all electronic slits are set equal in observations.

Due to the use of electronic slits, only data ranges necessary in further calculations participate in the work, being selected from the spectrum intensities recorded by the entire CCD array. This allows one to reduce significantly the time required for reading out the necessary information and the memory capacity required for memorizing and storing this information. Note that the signal values calculated from the radiation intensity values taken off the CCD array are written to the hard disk (rather than the intensities themselves), thus reducing the filled memory space and the time of further processing.

**OBSERVATION RESULTS**

The two most widespread types of observations in solar research practice were performed on the linear CCD array in 1999: (1) observation of time changes in the differential ray velocity in order to record periodic oscillations of the solar plasma; (2) scans across a sunspot or an active area aimed at obtaining the spatial distributions of the longitudinal magnetic-field component and ray velocity. In September 2000, several test observations representing instantaneous sections across an active area were performed with a CCD matrix.

The Fe I line of ionized iron ($\lambda = 525.02$ nm) was observed in spectra measured with both a linear CCD array and a CCD matrix. This is a purely photospheric line with an equivalent width of $\sim 12$ pm and the Lande splitting factor characterizing the degree of magnetic sensitivity and measured in dimensionless units equal to three. The majority of magnetic field measurements in various observatories all over the world were accomplished with this line.

Observations of the second type on a linear CCD array were performed simultaneously at two lines: H$\beta$ (486.1 nm) and Ni I (485.7 nm). The altitude of formation of the first line core corresponds to the height of the lower chromosphere, the core of the second line forms in the photosphere, and their half-widths are 750 and 10 pm, respectively. Most of the observations of the velocity variations with time were carried out with a 10-s recording time constant.

Figure 2a presents a time series of the differential ray velocity measured at the center of the disk in the undisturbed photosphere in a line of 525.02 nm (obtained with a guide and tracking). Oscillations with a 5-min period ($\sim 3$ mHz), which are characteristic of the solar photosphere, are clearly pronounced in the record. A similar time series obtained with the same CCD array in the mode of Doppler compensator imitation is shown in Fig. 2c.

A higher noise level in the second record, as compared to that in the first one (Fig. 2a), is obvious. This is also demonstrated by their spectra (Figs. 2b and 2d, respectively). This is due to the effect of the internal instabilities of an astronomic grating spectrograph (thermal inhomogeneities of the air mass filling the spectrograph’s volume, local pressure variations, residual strains of movable mechanical parts, etc.).

In order to determine more precisely the gain achieved upon noise suppression in the differential method, a similar observation was performed in the oxygen line of the Earth atmosphere ($\lambda = 687.4$ nm). As is known, telluric lines can be employed as natural references in measurements of Doppler velocities with an accuracy of up to 5–10 m/s [3].